Session No. 4

Course Title: Earthquake Hazard Management

Session 4: **Earthquake Hazard and Risk in the U.S.**

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Time: 90 minutes

Objectives:

4.1 Distinguish between seismic hazard and seismic risk.

4.2 Discuss the seismic hazard of the United States, and explain how seismic hazard varies among the major regions of the country.

4.3 Describe recent and current paleoseismological studies that provide new insight into the seismic hazard evaluation of regions of infrequent seismicity (Eastern U.S., Central U.S., etc.).

4.4 Explain why seismic *hazard* is lower in the eastern U.S. compared to the western U.S., but the seismic *risk* is comparable.

Scope:

In this session, the instructor will begin with a discussion of the definitions of seismic h**azard** and seismic **risk**. The difference between the two should be clearly distinguished, as outlined in the notes. The instructor should then discuss the seismic hazard in the United States and refer back to the national seismic hazard maps discussed in the previous lecture (Session 3). The lecture should then progress to a discussion of the seismic risk in the United States. A useful exercise is to first query the students as to their ideas of how the earthquake risk in the eastern U.S. compares to that of the western U.S., and then present specific scientific and engineering findings that must be considered in such a risk comparison. The lecture format will be mostly conventional lecture with the use of electronic visuals. The session will involve one in-class group discussion where the students are broken up into teams to discuss questions posed by the instructor.

The main purpose of this session is to provide the students with a basic understanding of earthquake hazard and risk and to illustrate how these parameters vary across the U.S.. It should be recognized that the "experts" in quantifying earthquake hazards and risks are seismologists and engineers. It is unlikely that emergency managers will be directly involved in such scientific and engineering studies. However, it is important that emergency managers have at least a basic familiarity of the fundamental issues involved with determining the potential losses from earthquake hazards.

A suggested classroom reading and homework assignment for this session are included. These assignments should be distributed following the completion of the lecture. Electronic visuals presented in these notes are included in the accompanying file: “Session 4 Electronic Visuals.ppt” and should be used to enhance the lecture presentation.

Readings:

Required student reading:

http://quake.wr.usgs.gov/prepare/factsheets/RiskMaps/

Required instructor reading and resources:

http://quake.wr.usgs.gov/prepare/factsheets/RiskMaps/

Yeats, R. S., Sieh, K., and C. R. Allen, 1997. *The Geology of Earthquakes*, Oxford University Press, Introduction, Chapters 1, 2.

Supplemental background reading material provided in the accompanying file: “Session 4 Background Reading.doc.”

Visual aids provided in the accompanying file: “Session 4- Electronic Visuals.ppt”

Other useful Internet web pages:

http://www.usgs.gov
http://earthquake.usgs.gov/image_glossary/

Electronic visuals included: [*see Session 4 Electronic Visuals.ppt*]

4.1 Map with bar graphs showing relative hazard
4.2 Generalized USGS seismic hazard map
4.3 Plot showing peak acceleration
4.4 Modified Mercalli Intensity Contours
4.5 Comparisons of affected areas of similar-sized earthquakes
4.6 Average population density in US
4.7 Example of seismically weak infrastructure common in CEUS

Additional visuals also are included for the in-class discussion and are to be used at the discretion of the instructor:

4.8 Central/Eastern (CEUS) locations where paleoseismological studies have been performed
4.9 Photo of liquefaction
4.10 Photo of fossilized liquefaction
4.11 Schematic of typical ancient liquefaction features
4.12 Table showing ages of liquefaction features in Charleston, SC

Note that many of the graphics used for this material were obtained from the United States Geological Survey (USGS) and are in the public domain and not subject to copyright. Appropriate credit is given for USGS-produced graphics. For information on their use policy, see: http://sfbay.wr.usgs.gov/access/copyright.html.

Handouts included:

Handout 4.1 Classroom Reading Assignment 4.1
Handout 4.2 Homework Assignment 4.1

General Requirements:

Special Note: *The information presented in this section is technical in nature and additional background study will be required by instructors with non-scientific backgrounds. In some cases, the instructor may wish to enlist the aid of an outside expert, such as faculty from a geological sciences or engineering department, to teach this material. While some instructors may alternatively elect to reduce the technical content presented, the concepts are important for a complete understanding of earthquakes and the nature of the hazard they pose. Therefore the instructor should cover as much of this material as feasible, and make adaptations where appropriate as the makeup of the class and availability of outside lecturers dictates.*

The instructor should distribute the class reading assignment following the end of the session. This assignment outlines how seismic hazards are determined in certain regions where few earthquakes have occurred, little is known about the actual potential for damaging earthquakes (intraplate regions, etc.), and where the historical record does not provide an accurate picture of the seismicity. This information is scientific in nature and the instructor and students may not be familiar with this work. However, the main purpose is to provide "color" and pique interest. Depending upon the comfort level of the instructor with this material (i.e., based on Internet research, etc.), an excellent discussion could occur on the subject of paleoseismology which has been used in many areas to provide earthquake data extending far back into prehistoric times. However, a class discussion is not necessarily required as this material is covered on the accompanying homework assignment. Also, the information provided in this section will overlap the lecture material from Session 3 in some places. This should provide additional opportunities for absorbing this material.

The instructor can simply distribute the class reading assignment (about 20 minutes in duration) as a handout, or he/she may choose to present this material as electronic visuals. In the latter case, cues for electronic visuals are provided in the handout file, and the electronic visuals are contained in the accompanying file: Session 4 - Electronic Visuals.ppt, along with the visuals for the main lecture material. Alternatively, the instructor may wish to post the file electronically on the Internet for the students to download.

The homework assignment should be distributed at the end of the session and one week is sufficient for this to be completed.

Additional Requirements:

Computer and projector for electronic visuals.

Objective 4.1 Distinguish between seismic hazard and seismic risk

Requirements:

Present the material as lecture and encourage student input and discussion. Note that following the definition of seismic hazard and seismic risk, a cue (i.e., *Note to Instructor*) is given as to a suggested question to ask the students regarding seismic hazard and seismic risk in the eastern and western U.S.. This is designed to stimulate classroom discussion.

Remarks:

I. **Seismic *hazard* involves the *expected occurrence or likelihood* of future seismic events. Seismic hazard describes the likelihood for dangerous, earthquake-related natural phenomena to occur**.

A. **Definition**: "The probability that ground shaking or surface deformation will equal or exceed specified values at a site during a specified exposure time."

B. Example of output of a **seismic hazard analysis** could be a description of the intensity of shaking from an expected earthquake, or a map that shows levels of ground shaking intensity (usually in acceleration), in different parts of the country that have a certain probability of being exceeded. **The USGS seismic hazard maps discussed in Session 3 are a prime example of a seismic hazard assessment.**

II. **Seismic *risk* involves the *expected consequences or losses* of future seismic events (typically measured in lives and dollars); seismic risk describes the potential for phenomena to produce adverse consequences to society, such as loss of life, property, etc. Seismic risk is a probabilistic expression of the product of seismic hazard and its consequences; that is, it considers the probability of an event occurring and also the possible consequence of the event.**

A. **Definition:** The probability that the consequences of the earthquake hazard, **expressed in dollars or casualties**, will equal or exceed specified values at a site during a specific exposure time. Combines seismic hazard with the consequences of the earthquake; that is, the probability of an earthquake combined with the conditional probability that given the earthquake, what the damage will be.

B. Example of output from a **seismic risk study** could be the probability of a certain level of damage (and repair cost) to a structure, or loss of life due to an earthquake. In a very simplistic example: Suppose that during the lifetime of a structure there is a 20% probability of an earthquake occurring nearby that would produce peak horizontal ground accelerations that exceed 0.3g. Further suppose that if the peak ground accelerations exceed 0.3g, there will a 50% probability of severe building damage. Thus, the results of a risk analysis for this site would report that "**there is a 10% chance that severe damage will occur during the lifetime of this structure**."

III. Thus, a seismic hazard evaluation for a site or facility involves establishing expected earthquake ground motion design parameters (i.e., peak accelerations); and, then by assessing the vulnerability of the site and the facility under these ground motion parameters, the seismic risk for the site/facility can be estimated.

*[**Instructor note**: This is a good time to informally query the class: "In what region of the U.S. do you think the seismic hazard is higher, eastern or western U.S. ?" Then ask, "Where do you think the seismic risk is higher, eastern or western U.S.? Why do you think so?" The purpose is to set the stage for the conclusion at the end of the lecture which is the seismic hazard is indeed higher in the western U.S., as expected, but the seismic risk in the eastern U.S. is comparable to that in the western U.S.]*

Objective 4.2 Discuss the seismic hazard of the United States, and explain how seismic hazard varies among the major regions of the country.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented. (***Note to Instructor**: As mentioned in the Required Reading section, be sure to review the paper in the Background Reading: "Public Misconceptions about Faults and Earthquakes in The Eastern United States: Is It Our Own Fault?" This paper provides additional background for better command of this subject matter, especially for instructors unfamiliar with this material.)*

Electronic Visuals Included:

Electronic Visual 4.1 Map with bar graphs showing relative hazard
Electronic Visual 4.2 Generalized USGS seismic hazard map
Electronic Visual 4.3 Plot showing peak acceleration

Remarks:

I. What is the Seismic Risk in the U.S.?

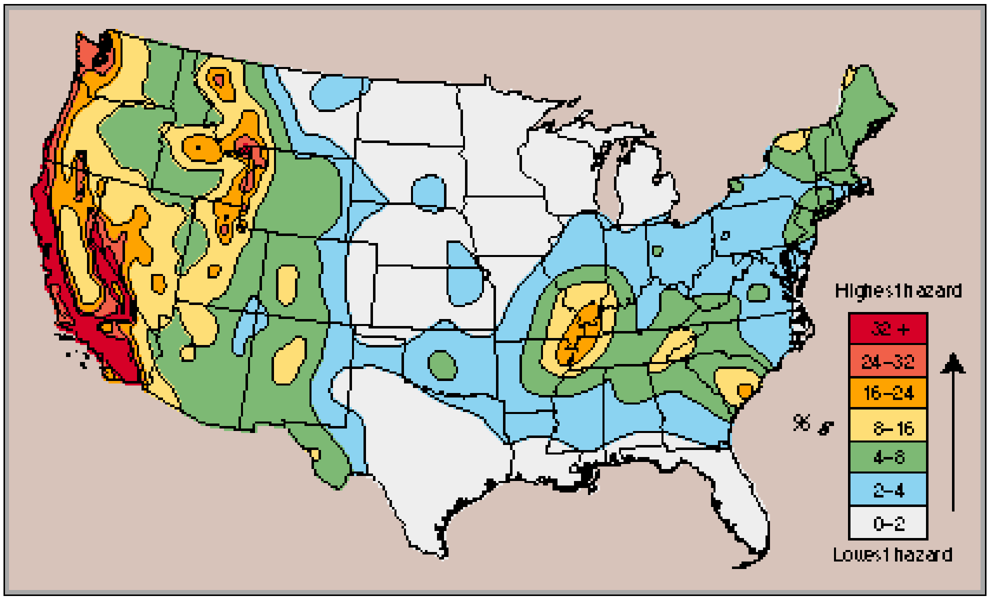
A. We must answer two questions to establish the risk:

1. First, what is the seismic hazard across the U.S.? [*Electronic Visual 4.1*]

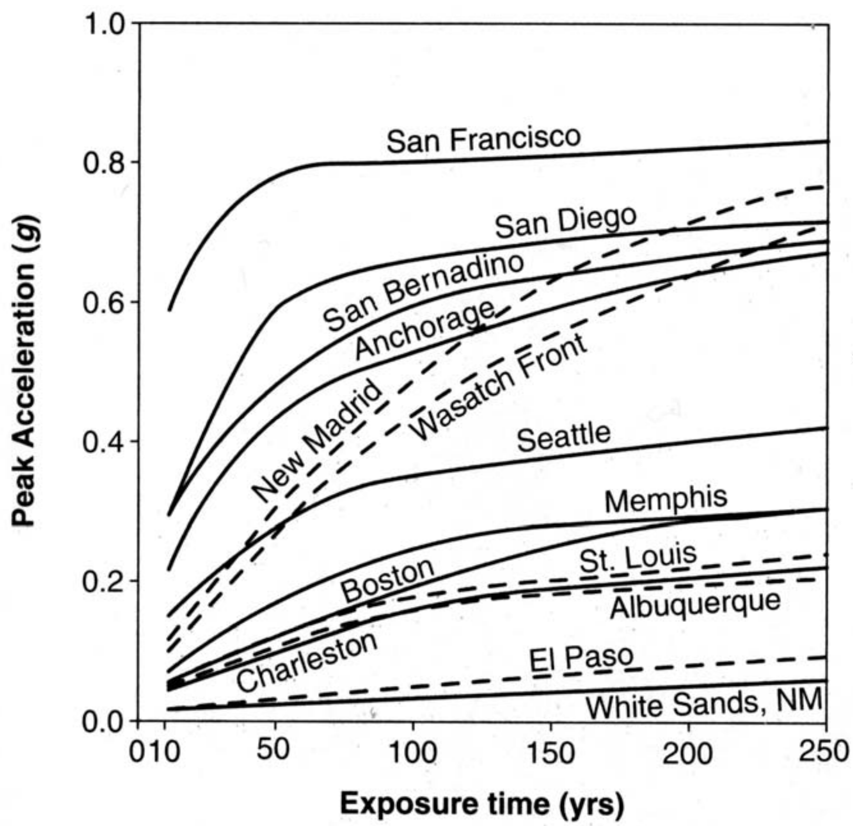
2. Then, what is the probability of damage given the occurrence of the seismic hazard(s)? [*Electronic Visual 4.2*]

B. The relative seismic hazard for some major U.S. cities is illustrated in the three visuals below. As expected, all the visuals indicate that the seismic hazard is highest in the western U.S. (due mainly to the more frequent occurrence of earthquakes). [*Electronic Visual 4.3*]

*Visual 4.1: Generalized map with bar graphs showing the relative hazard among some major U.S. cities. Credit: USGS (**Note: Baltimore and Charlotte are reversed in this visual.)***



Visual 4.2: Generalized USGS seismic hazard map for the United States (1996). Map shows peak ground accelerations (in % gravity) with a 10% probability of being exceeded in 50 years ("500-year earthquake").



Visual 4.3: Plot showing peak acceleration (a measure of seismic hazard) expected for various U.S. cities versus time. Credit: USGS

II. Now that we see the seismic hazard is highest in the western United States, what about the seismic *risk*? In other words, what is the likelihood of damage given an earthquake in each region? Consider the following factors about the eastern U.S.:

[***Instructor Note:*** *Mention that some of this material was covered earlier in Session 3*]

A. Although less frequent, there is evidence for recurring large earthquakes and the potential for many more.

B. Notably, the **central U.S.** has historical accounts of a number of great (M8+) earthquakes; in fact, the three main 1811-12 events were the largest ever in the continental U.S.. There is recent evidence that large prehistoric earthquakes also have occurred in this region (i.e., Obermeier et al., 1992).

C. In the **southeast**: There have been a number of earthquakes in the range of M6, most notably the 1886 Charleston, SC event which was M7.3. Of particular significance, paleoseismic studies in this region indicate recurring large prehistoric earthquakes possibly as far back as 30,000 years. Strong evidence supports the occurrence of at least five large earthquakes in the last 6,000 or so years (Talwani and Schaeffer, 2001; Obermeier et al., 1987; Martin and Clough, 1994).

Objective 4.3 Describe recent and current paleoseismological studies that provide new insight into the seismic hazard evaluation of regions of infrequent seismicity (eastern U.S., central U.S., etc.)

Requirements:

Present the material as lecture, supplement by electronic visuals. Encourage student input and discussion.

Electronic Visuals Included:

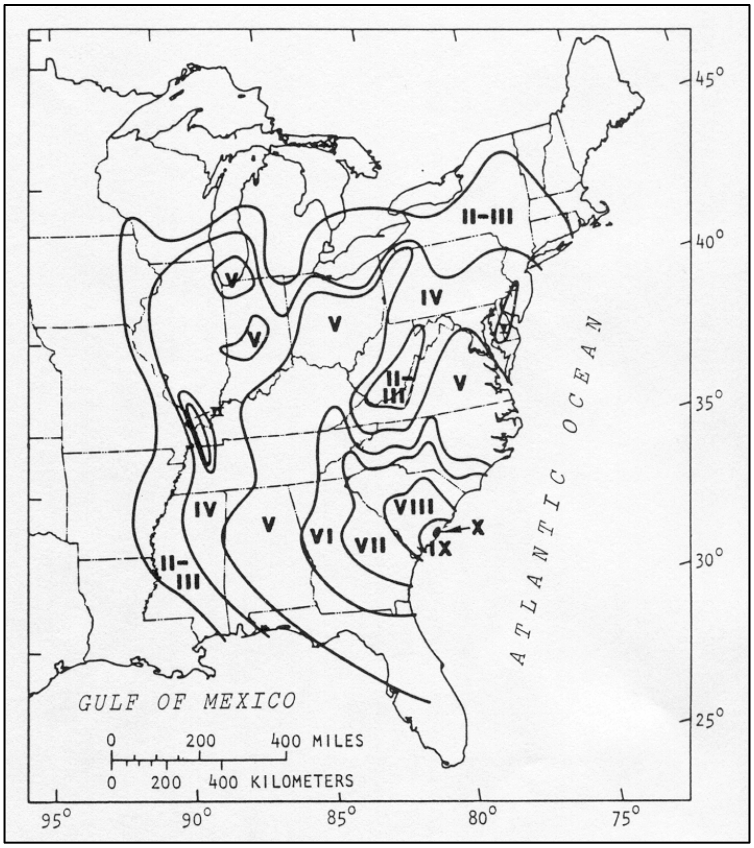
Electronic Visual 4.4 Map showing Modified Mercalli Intensity (MMI) contours from the 1886 Charleston, SC earthquake
Electronic Visual 4.5 Comparisons of affected areas of similar-sized earthquakes
Electronic Visual 4.6 Average population density in U.S.
Electronic Visual 4.7 Example of seismically weak infrastructure common in CEUS

Remarks:

I. *Attenuation* (decay of earthquake energy versus distance) in the eastern U.S. is less than that in the western U.S..

A. This is related to the rock properties – the bedrock in the eastern U.S. is harder, colder, and less fractured relative to western U.S. regions located close to active plate boundaries – and, therefore the rock is much more efficient in transmitting earthquake waves.

B. For instance, during the 1886 Charleston, SC earthquake, the motions were felt over more than half of the United States, as shown in Visual 4.4. The event was clearly felt in Boston, New York, Chicago, and Cuba. The motion would not have been felt this far away if the earthquake were located in the western U.S.. [*Electronic Visual 4.4*]

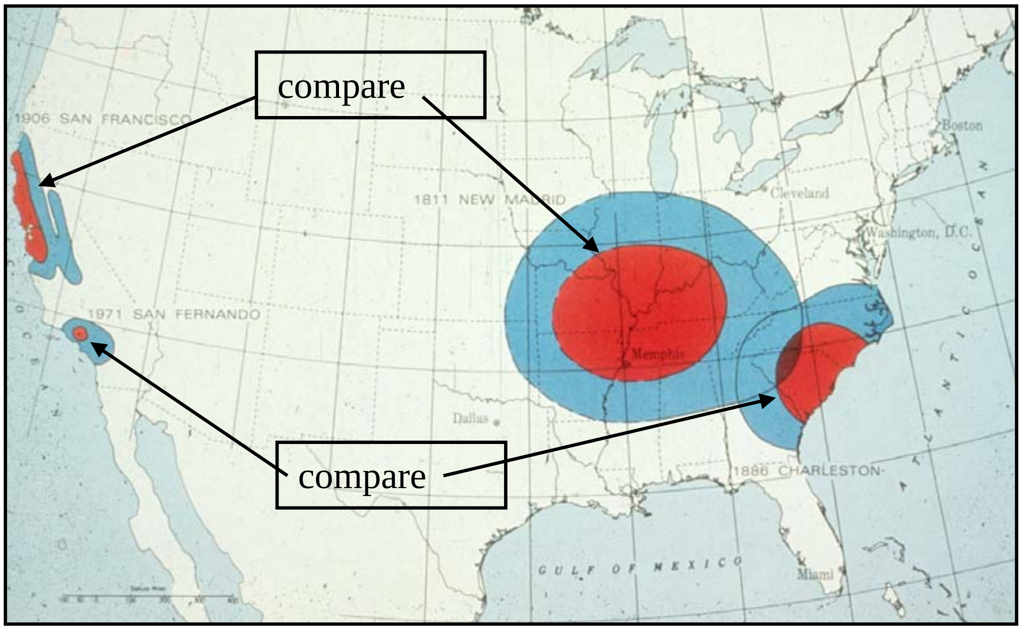


Visual 4.4: Map showing Modified Mercalli Intensity (MMI) Contours from the 1886 Charleston, SC earthquake. Motions are clearly felt at MMIs of III and greater.

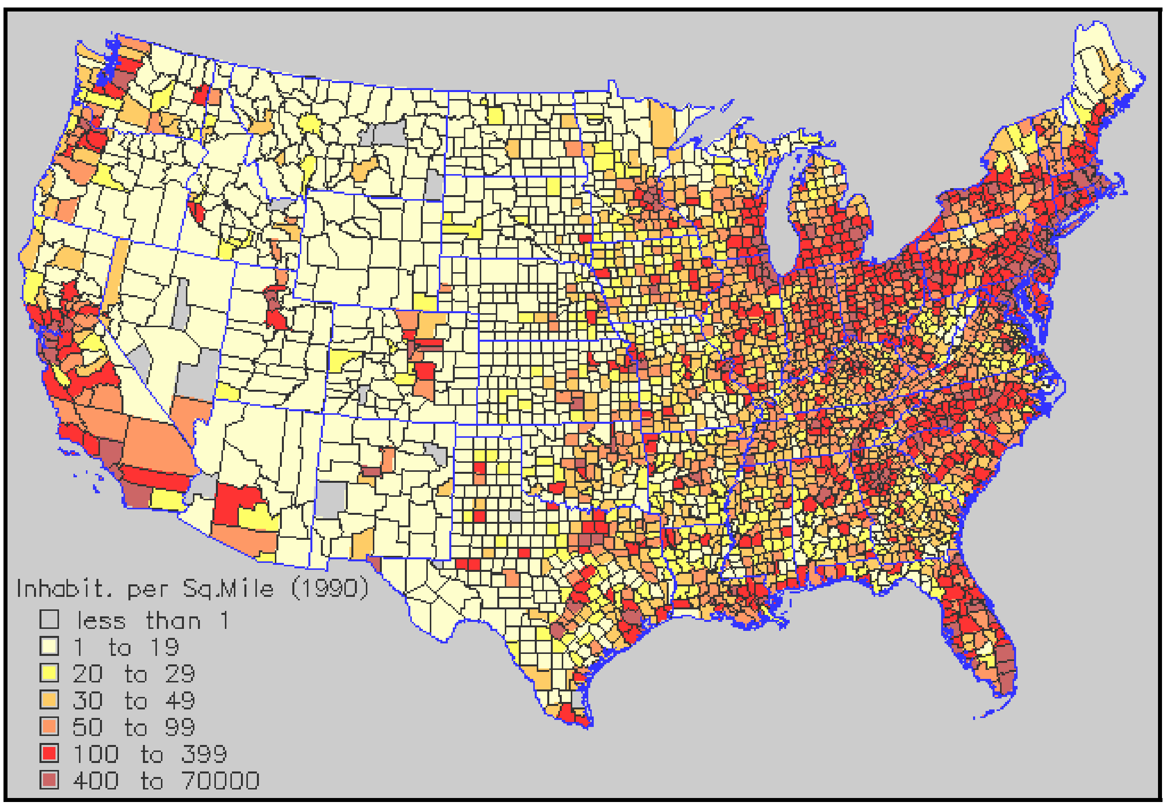
II. If we compare the size of the areas that similar-sized earthquakes have affected in the eastern and western U.S., we see that the eastern earthquake affect much larger areas.

A. Given the same-sized earthquakes in the eastern and western U.S., the eastern event will affect a much larger area. [*Electronic Visual 4.5*]

B. The average population density is higher in the eastern U.S. than the western U.S.. Therefore, combined with the lower attenuation of ground motions, a greater number of people theoretically would be affected by an earthquake occurring in the eastern U.S. relative to the western U.S.. [*Electronic Visual 4.6*]



Visual 4.5: Map showing comparisons of affected areas from similar-sized earthquakes in the eastern and western U.S. Credit: USGS



Visual 4.6: Map showing average population density in the U.S; note higher overall density in the eastern U.S. (darker colors). Credit: US Census Bureau.

C. There is an abundance of weak, vulnerable infrastructure with little to no seismic protection in the eastern U.S.. Also, especially dangerous and weak structures have not been "weeded out" by smaller "warning" earthquakes such as the Northridge earthquake for the Los Angeles area; see example of seismically weak structure in Visual 4.7 below.

[**Note to Instructor:** *Emphasize here that the seismically weak infrastructure common in the eastern and central U.S. will be discussed in more detail in later sessions.*]

Visual 4.7: Example of seismically weak infrastructure common in CEUS. Failure of wall of unreinforced masonry building during the1989 Loma Prieta earthquake. Cars waiting in the alley below were crushed and occupants killed. This type of weak, non-ductile infrastructure is common in the central and eastern U.S. Photograph credit: J. Martin.

D. Seismic design practice in the eastern U.S. is still immature. Although the practice is evolving, seismic design standards and their application are relatively new.

E. There is much more uncertainty in terms of the causative seismic mechanisms – What are the causes of these intraplate events? We generally do not know with certainty. What is prudent for safe, economical designs? Since we do not really understand the mechanisms, do we really even know about all of the potential sources? (i.e., from an earthquake source standpoint, the geology in the coastal regions of northern GA and southern NC is not much different than that in coastal SC near Charleston. Can 1886-sized earthquakes also occur in these locations? We are not sure.)

F. There is a great deal of "human inertia." That is, because earthquakes are not frequently felt, there is more resistance to exercising mitigation and preparation measures – an "out-of-sight-out-of mind" type attitude.

Objective 4.4 Explain why seismic *hazard* is lower in the eastern U.S. compared to the western U.S., but the seismic *risk* is comparable

Requirements:

Present the material as lecture and encourage student input and discussion. The class reading assignment and homework should be distributed following this objective.

Handouts Included:

Handout 4.1 Classroom Reading Assignment 4.1
Handout 4.2 Homework Assignment 4.1

Remarks:

I. Considering the material presented thus far, what does it all mean with regard to seismic risk?

A. When all factors are considered and integrated, we conclude: *The seismic hazard is higher in the western U.S., but the seismic risk in the Eastern U.S. is comparable!*

B. Issues To Think About:

1. Good analogy: Kobe is to Tokyo as the central/eastern U.S. is to the western U.S. (in terms of seismicity, infrastructure seismic resilience, and building practices, etc.)

2. Remember that **the most expensive U.S. natural disaster (Northridge, CA earthquake ~$30 billion) occurred on a relatively minor fault (that**

was given much less attention and poorly identified) located away from the central area of Los Angeles!

3. What does the Northridge earthquake indicate in terms of the potential losses from earthquake hazards relative to other hazards?

[***Instructor Note***: *Handout Classroom Reading Assignment (Handout 4.1) and Homework Assignment 4.1 now. The Classroom Reading Assignment/Discussion utilizes Visuals 4.8 – 4.12 included in the Electronic Visuals file for this session.*]

References Utilized:

Martin, J.R., and G.W. Clough., 1994. "Seismic Parameters from Liquefaction Evidence," *Journal of Geotechnical Engineering, ASCE*, August, 1994, pp. 1345-1361.

Martin, J.R., and E.C. Pond,1993. "Seismic Analysis of Relict Liquefaction Features in Regions of Infrequent Seismicity," *Transportation Research Board Record No. 1411,* National Research Council, January, 1993, pp. 53-60.

Natural Resources Canada (2004), data and figure from website at: http://www.seismo.nrcan.gc.ca/historic_eq/imageschar/charlocmap.jpg

Obermeier, S. F.1998. "Seismic Liquefaction Features: Examples from Paleoseismic Investigations in the Continental United States," *Open-File Report* 98-488, U.S. Geological Survey, Reston, VA.

Obermeier, S. F., Weems, R. E., and R. B. Jacobson. 1987. "Earthquake-Induced Liquefaction Features in the Coastal South Carolina Region," *U.S. Geol. Surv. Open File Report 87-504.*

Obermeier, S. F., Martin, J.R., Frankel, A.D., Youd, T.L., Munson, P.J., Munson, C.A., and E.C. Pond, 1992. "Liquefaction Evidence for Strong Holocene Earthquake(s) in the Wabash Valley of Southern Indiana-Illinois, with a Preliminary Estimate of Magnitude," *U.S. Geological Survey Professional Paper 1536*, May, 1992, pp. 1-27.

Obermeier, S.F., Munson, P.J., Munson, C.A., Martin, J.R., Youd, T.L., and N. K.Bluer.1992. "Liquefaction Evidence for a Strong Holocene Earthquake in the Wabash Valley of Indiana-Illinois," *Seismological Research Letters, Journal of the Eastern Section of the Seismological Society of America*, Vol. 63, No. 3, July-September, 1992, pp. 321-335.

Pond, E. and J. R. Martin.1997. "Estimated Magnitudes and Ground Motions Characteristics Associated with Prehistoric Earthquakes in the Wabash Valley Region of the Central United States," *Journal of Seismological Research Letters*, Seismological Society of America (Eastern and Central U.S.) Vol. 68, No. 4, pp. 611-623.

Talwani, P., and W. Schaeffer. 2001. “Recurrence Rates of Large Earthquakes in the South Carolina Coastal Plain Based on Paleoliquefaction Data.” *Journal of Geophysical Research* (JGR), 106, pp. 621-642.

US Geological Survey (USGS), data and various figures from website at: http://quake.wr.usgs.gov/prepare/factsheets/RiskMaps/

US Census Bureau (USCB), data and figure from website at: http://www.census.gov

Yeats, R. S., Sieh, K., and C. R. Allen. 1997. *The Geology of Earthquakes*, Oxford University Press,.